PROPER MOTION CATALOGS

By R. H. Tucker

Two volumes of proper motions have recently been received at the Observatory. Each has its particular scope. Nyren's "Proper Motions of 633 Stars," gives the computed values for a selected list of stars, nearly all of them being new, and mainly on this account nearly all of them of small size. Bossert's "Proper Motions of 5071 Stars," includes all stars for which reliable values of proper motion of sensible amount have been computed, up to date.

The Nyren catalog was prepared in order to furnish the places and proper motions of the stars for a fundamental list, to be used in reducing the photographic measures of star places all over the sky. The aim was to provide at least one star, between fifth and seventh magnitude, on each photographic plate of 25 square degrees, between the north pole and 30° south declination. From −30° to the south pole the places and proper motions of the required stars are to be derived by Prof. Hough. A considerable proportion of the 1553 stars required for Nyren's list had already been discussed for proper motion, but there remained between 600 and 700 for which new values were to be computed. Some, for which the new computations were made, were later found among the other authorities, and for some of the stars there were not sufficient old observations to give reliable results for proper motion.

The system adopted was that of the "New Fundamental Catalogue" of Dr. Peters, and all the observations were reduced to this system, as far as possible. All the stars were observed in recent years at the Poulkova Observatory, but owing to the break in the activities of that institution the results have been published in Volume 60 of the Swedish Academy of Sciences, for 1920. All available old catalogs have been employed in deriving the proper motions, going back more than a century, to those of Federenko, Piazzi and the *Histoire Celeste*. Often there were more than two dozen catalogs, from which observations could be obtained, for individual stars. Half that number give a good determination. But for a few of the stars, observations were found in only three or four catalogs, and the resulting computed values are quite uncertain, and sometimes of entirely doubtful character.

The results of any combination of old observations depend, to a large extent, upon the respective weights assigned by the computor.

This is largely a matter of judgment, and scarcely possible of exact conformity with the theory which would base the weights strictly upon probable errors of observation. The recent Poulkova observations are given a uniform weight of 20, for from ten to twenty or more observations. There are over eighty star places used from the *Lick Observatory Publications*, mainly from the "Zodiacal Catalogue" of Vol. X. These have been assigned weights, from 5 for two observations, to 8 for six observations. One star observed by me at Albany in the year 1882 has been included, with weight 4 for two observations.

A comparison of Nyren's values with those of other authorities, for sixty of the stars, gives probable errors for the individual authorities of approximately $\pm 0^s.0011$ and $\pm 0''.012$, in the two coordinates. The computed proper motions are given to four places of decimals in right ascension, and to three places in declination. These units are desirable for full precision in carrying forward the results of computation. But the probable errors may evidently be as great as ten times the final unit of decimals. Nearly the same material would have been used in the various individual computations, but differences are introduced by the systematic corrections applied to the old observations, and by the weights assigned. It is doubtful if values of proper motion of $0''.01$ or less can be definitely adopted for any but our best determined stars, such as those of our fundamental lists.

In the treatment of a large mass of results we may be justified in dealing with units of value much smaller than could be adopted for single stars, as representing a sensible amount of proper motion. The average values of proper motion for this list are $\pm 0^s.0029$ in right ascension, and $\pm 0''.029$ in declination. Omitting individual values above $0^s.01$ in right ascension, and $0''.1$ in declination, the averages are $\pm 0^s.0025$, and $\pm 0''.024$. There were forty of such values, or a proportion of one in thirty proper motions. The count shows 47% less than $0^s.002$, and $0''.02$, which is about the proportion to be expected if the individual proper motions follow approximately the distribution, in size, of a probable error solution. On the other hand, there are 28% that are smaller than $0^s.001$ in right ascension, and $0''.01$ in declination, values so small that it is doubtful if real proper motions are represented by the computed results. The largest proper motions listed are $+0^s.021$ in right ascension, and $-0''.20$ in declination. Since these are newly deter-

mined proper motions there are no exceptionally large values, as these would have been detected previously, and would have been included in earlier lists. Nearly one-half (44%) of the stars are south of the equator, in the area to $-30°$ declination. This proportion is due to the relative lack of early observations in that part of the sky, which had discouraged the computation of proper motion. The Cordoba catalogs are a strong contribution to this area, tho the epoch is less than half a century earlier than that of the latest available observations.

For deriving an approximate value of the parallactic effect of the solar motion upon the places of these stars, the individual proper motions were combined in groups of six hours each, and in the zones: 70° to 90°, 50° to 70°, 30° to 50°, 0° to $+30°$ and 0° to $-30°$. The respective numbers employed in the zones were: 26, 37, 84, 186 and 262. The six hour combinations have total numbers of 147, 152, 163 and 134, respectively. Individual values that were quite uncertain were not included in the means. The solution from each zone was weighted according to the number of stars, and the following values for the parallactic motion were derived. From all the proper motions, $0''.039$ from the right ascensions and $0''.031$ from the declinations, mean $0''.035$. Including only the proper motions not exceeding $0^s.01$ and $0''.1$ the similar solutions give $0''.033$ from right ascensions, and $0''.025$ from declinations, mean $0''.029$. These parallactic motions represent the average effects upon stars of the type fifth to seventh magnitude, with proper motion in either coordinate not exceeding $0''.2$ in the first solution, and not exceeding $0''.1$ in the second. Since the base line of about 380 million miles is four times the radius of the orbit of the Earth, the average stellar parallax of these stars would be one-fourth of the above values of the parallactic motion. For a sensible amount of parallax, measurable by our present methods, stars of exceptionally large proper motion would naturally be selected for investigation.

The catalog of Bossert probably includes all the known proper motions that are of sensible size, and that are reliable as to values, up to the time of the death of the author. It is a compilation of all the sources of information in the form of computations, rather than any new contribution to individual results. All competent authorities that had published any extensive material appear to have been drawn upon. The catalog was in manuscript form at the death of

the author, Joseph Bossert, and the publication has been carried out by M. L. Schulhof, who had previously collaborated with Bossert in compiling lists of proper motions. The general introduction, following that of Bossert, was written by Schulhof, who has completed also the very extensive Notes, begun by the original author.

The lowest limit in size of individual proper motion has generally been taken at 0″.05, for the resultant from the motions in both coordinates, but for many well determined stars the lowest limit has been adopted at 0″.01. The catalog gives the proper motion in each coordinate, and the resultant value in seconds of arc from the two, with the direction of this resultant. The authority for the adopted value is given also. In the Notes to the catalog a list of separate values is given for many stars. An excessive amount of computation has often been done on some particular star. In the Notes the last authority quoted has been given the preference.

Extensive Notes, which might be considered as an appendix, have been introduced at the end of the volume, dealing with proper motions derived from measures of wide double stars, with spectroscopic binaries, the distribution of stars according to spectral type, the relation of speed to type, parallaxes, star streams, radial velocities, and with nebulae and clusters.

With some additional stars from the list of Nyren, which would fall within the scope of this volume, there would be about six thousand known proper motions of sensible size. The first attempts to compute proper motions date back to late in the eighteenth century. Early in the nineteenth century there had been about six hundred computed, but perhaps only a third of that number were reasonably exact. The Paris Observatory volume for 1888 gave over 2600, of which perhaps 2000 were reliable. In the last thirty years that number has been trebled, but no great increase may be expected in the immediate future, since the large proper motions have mostly been detected for all the brighter classes of stars. There will be an increase in the number of known proper motions for the stars of eighth and ninth magnitude, as sufficient interval elapses from the earliest precise observations of these stars. And evidently stars too faint to be observed with our meridian instruments may show large proper motion in some instances, such as that of the tenth magnitude star, which was detected by Barnard.

Bossert's earlier lists of proper motions have been much consulted in the cases of suspected proper motion, and his work in that

line has extended over a generation. A small table in the catalog gives the following summary of the individual proper motions of large size:

1 star	of 8″
1	7 to 8
1	6 to 7
2	5 to 6
5	4 to 5
9	3 to 4
15	2 to 3
64	1 to 2
5573	below 1

There are 98 stars, or less than two per cent, that are above 1″.

I have summed up the individual resultant proper motions in classes according to brightness, and the following table will give the results, which present some interesting characteristics. The table gives the class, its mean magnitude, the number of stars, the percentage of the total number listed, the average proper motion including all values, the number of values above 1″ in each class, and the average proper motion when such values are omitted. For the brightest stars these average proper motions are final, since practically all values have been included. For the fainter classes large numbers of small proper motions have not been detected, and the average value for stars of such a class should be based upon the total number. The two final columns represent such an adjustment. The stars of known proper motions are a percentage of all the stars in the sky of that class. This percentage is given in the column next to the last, and the last column gives the average, estimated on this basis. Up to the sixth magnitude the proper motions have been generally computed, and the final column represents the type probably with precision. For the stars of the last three classes the final averages should probably be slightly increased, to represent the large number of small proper motions not yet detected. The average for the magnitude 7.5 may possibly be close to 0″.01, and that for the stars 8 to 9 inclusive might easily be double the value tabulated below.

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Limit	Mag.	No.	%	Mean	Omit	Mean	% Sky	Average
0 to 3	2.1	96	02	0″.27	5	0″.168	1.00	0″.17
3 and 4	4.3	634	11	0 .20	15	0 .150	95	0 .14
5 to 6	5.5	751	13	0 .17	11	0 .141	30	0 .04
6 to 7	6.5	1266	23	0 .18	19	0 .158	14	0 .02
7 to 8	7.5	1399	25	0 .20	15	0 .186	04	0 .007
8 to 9	8.4	1319	23	0 .25	21	0 .208	01	0 .002
9 up	9.1	186	03	0 .34	12	0 .223		

The proper motions of sensible size appear to be well distributed among all the classes of stars. The number of values of extraordinary size is also well distributed, an average of 14 above 1″ for a class. This indicates that stars of all grades of brightness may be included in any limitation of space, if we are to take the proper motion of a star as an approximate test of distance. Of course the stars may have a wide variety of individual speeds, but the test is still of general application.

The average proper motion of all the stars in the catalog is ±0″.21. If the count be limited to those of 1″ or less, the average is ±0″.176. The exclusion of motions as large as 1″, which is about six times the size of the remaining proper motions, would be justified, in drawing general conclusions from the individual values of proper motion.

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